Project ID# eems009
Pillar(s) Urban Science

U.S. DEPARTMENT OF ENERGY
SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

Modeling and Simulation of Automated Mobility Districts

Venu Garikapati, NREL
DOE Vehicle Technologies Office
2019 Vehicle Technologies Office Annual Merit Review
June 11, 2019

Argonne NATIONAL LABORATORY | INL Idaho National Laboratory | BERKELEY LAB | OAK RIDGE National Laboratory | NREL NATIONAL RENEWABLE ENERGY LABORATORY

OVERVIEW

Timeline

- Project start date: 10/1/2016
- Project end date: 9/30/2019
- Percent complete: 70% (FY18)

Budget

- Total project funding
  - DOE share: $860K
  - Contractor share: $0
- Funding for FY 2018: $320K
- Funding for FY 2019: $250K

Barriers

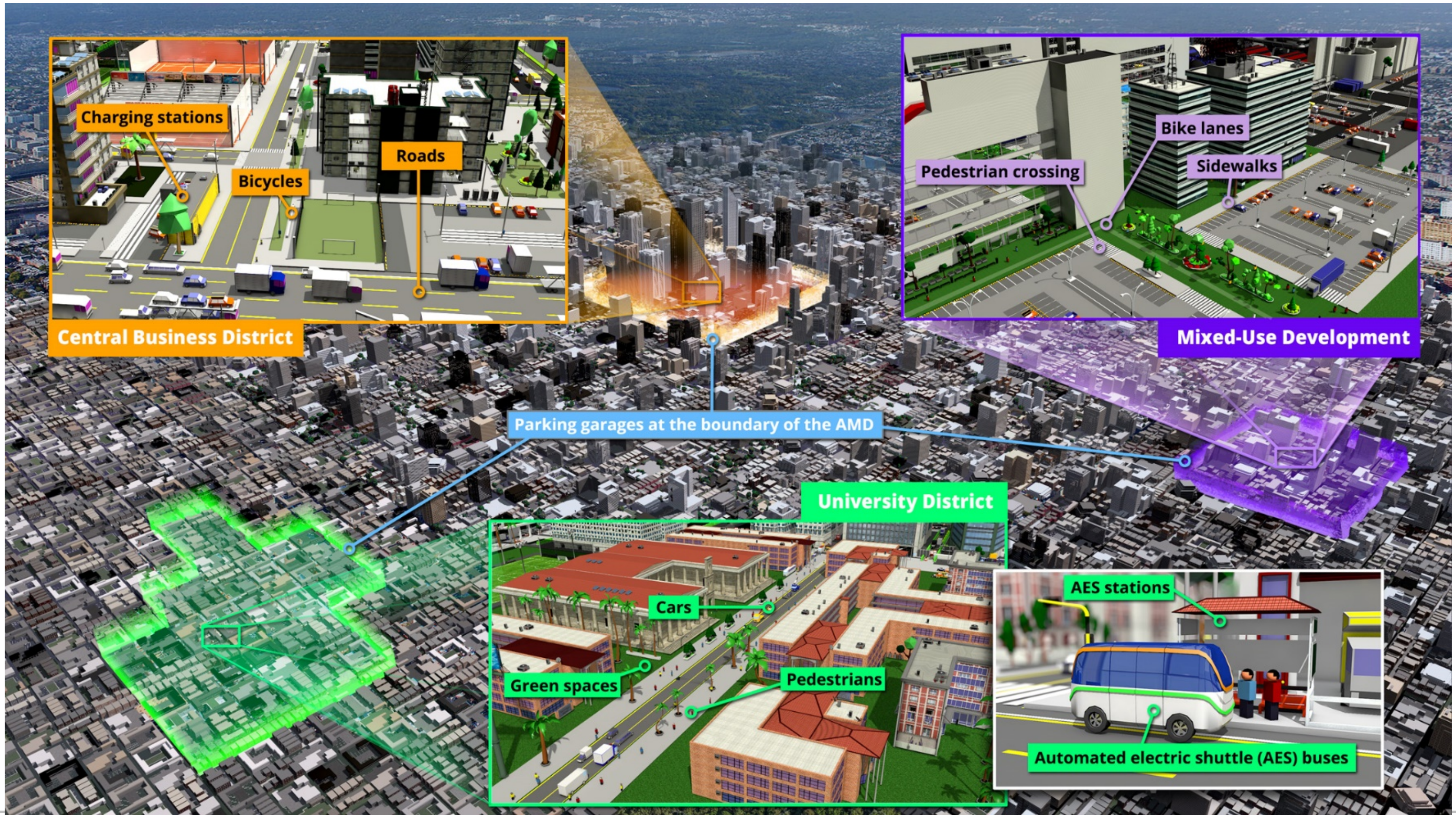
- Design, and simulation methodologies for automated mobility districts (AMDs).
- Computational models for connected/automated vehicles (CAVs).
- Lack of real-world data to support AMD modeling efforts.

Partners

- SMART Mobility Laboratory Consortium:
  - National Renewable Energy Lab (NREL)
  - Oak Ridge National Laboratory (ORNL)
  - Idaho National Laboratory (INL)
- Greenville County, South Carolina
- University of South Carolina (sub)
- Automated Mobility Services, LLC (sub)
- Mineta Transportation Institute

WHAT IS AN AUTOMATED MOBILITY DISTRICT?

An AMD is a campus-sized implementation of CAV technology to realize the full benefits of a fully electric automated mobility service within a confined region or district.



RELEVANCE

Source: https://www.energy.gov/eere/articles/energy-and-transportation-departments-commit-supporting-cities-future

The Energy Efficient Mobility Systems (EEMS) Program envisions an ***affordable, efficient, safe, and accessible*** transportation future in which mobility is decoupled from energy consumption. The program will conduct ***early-stage R&D*** at the vehicle, traveler, and system levels.

- **Project Objectives**
  - Quantify the net mobility gains and energy impacts of automated, connected, electric and/or shared (ACES) vehicles deployed in dense urban districts
  - Develop modeling capabilities for VTO to estimate the energy and environmental effects of AMDs

Intra-District Impacts	Inter-Regional Impacts	Boundary Issues/Effects
• Mobility and energy of AMD fleet • Land use changes.	• Modal choice • Route choice • Activity choice.	• Mode transfer/ parking • Boundary services • TNCs, car sharing/rental.

  - Integrate AMD model into existing regional travel models to simulate AMDs as a “special generator” in the region to quantify energy and mobility impacts.

TNC: transportation network company

MILESTONES

Month/Year	Description of Milestone or Go/No-Go Decision	Status
June 2018	Conference paper, "Quantifying the Mobility and Energy Benefits of Automated Mobility Districts Using Microscopic Traffic Simulation," presented at the American Society of Civil Engineers – International Conference on Transportation and Development conference held in Pittsburgh, PA	Complete
September 2018	Exercise the AMD modeling toolkit for a real-world deployment	Complete (AMD Simulation for Greenville, SC)
February 2019	Journal paper, "Route and Fleet Size Optimization in an Automated Mobility District: Serving On-demand Mobility with Automated Electric Shuttles," submitted to *Transportation Research – Part C*	Complete
August 2019	Integration of Mode Choice Model into AMD toolkit Integration of Optimization module into AMD toolkit	On Schedule

APPROACH: TASKS

Name	Description
Fleet Optimization Module	Develop a fleet optimization module for integration with the toolkit—determining the optimal number and capacity of shuttles and operational configuration to serve a given demand.
Mode Choice Model	Develop a mode choice model that is responsive to shuttle operations (frequency, capacity) and regional transportation infrastructure.
Application of AMD Toolkit	Exercise the AMD toolkit in at least one additional deployment location to Greenville, SC.

APPROACH: KEY RESEARCH QUESTIONS

- Vehicle Ownership
  - How will **automation** and **mobility as a service** promote a shift from private ownership and use to shared ownership and use, and what are the **implications for vehicle miles traveled and therefore energy use**?
- Behavior
  - Will districts that **adopt full, public, automated mobility** promote and be, in net, less energy-intensive than districts that do not do so?
- Investigating appropriateness of **shared automated mobility at different urban (density) scales**
  - What are characteristics to indicate AMDs will be of greater benefit?
- Helping AMD deployments with **operational configuration decisions**
  - Optimal number of shuttles, routes, battery capacity, operating frequency

APPROACH: AMD SIMULATION TOOLKIT → MODEL FLOW

Travel Demand

- Origin-Destination data from regional travel demand model
- Local surveys or counts
- Induced travel demand
- Passenger travel behavior; adoption rates

FY18

SUMO

(Mobility Analysis)

- SUMO — Simulator of Urban Mobility
- Carries out the network simulation of vehicles
- SUMO will output travel trajectories

FY18

FASTSim

(Energy Analysis)

- FASTSim — Future Automotive Systems Technology Simulator
- FASTSim will output vehicle energy consumption

FY18

Mode Choice Modeling

FY19

- Initially tagged to be developed based on user surveys from Greenville
- Resorting to a model based on existing literature owing to lack of data from Greenville

Optimization Module

FY19

- Fleet size: How many electric shuttle units will be required?
- Routes: What are the optimal routes that minimize travel time and energy consumption?
- How do we find solutions that meet customers' expected waiting time and overall trip duration?

APPROACH: AMD TOOLKIT – INPUTS/OUTPUTS FOR THE OPTIMIZATION MODULE

INPUT

Road network:
Graph (nodes, edges)

On-demand requests:
Origin, destination, preferred waiting time window, departure time window

Cost:
Time-dependent generalized travel cost at link level

AES configurations:
Passenger capacity and distance covered by single charge

OPTIMIZATION

Minimize the generalized travel cost

Find the minimum number of vehicles/AES

Meet waiting time threshold:
A customer may not wait more than 120 seconds before an AES picks her up from the origin node

Meet single charge distance constraint:
An AES only covers the distance allowed by a single charge

OUTPUT

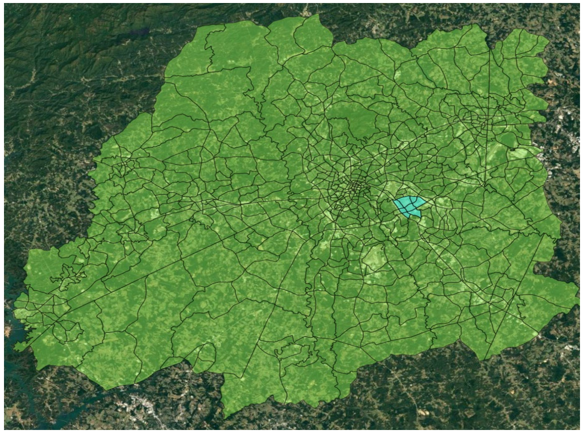
Minimum number of AES units required that meet on-demand requests with specified constraints

Optimal routes for all AES units in the network

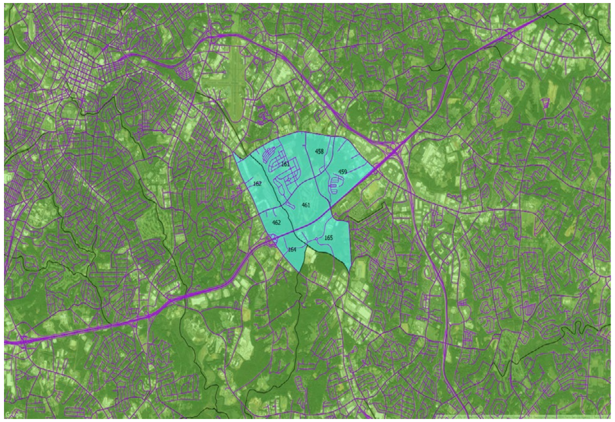
Total energy consumption (kWh) by the AES units

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

- AMD (hypothetical) network modeling and simulation – **Completed**
- Conference paper presented at the ASCE – ICTD 2018 conference [**Best Poster**]
- Integration with FASTSim – **Done**
- Memorandum of Understanding (MOU) with Greenville and Non-Disclosure Agreement (NDA) with Robotic Research – **In place**
- Greenville AMD modeling and simulation – **Underway**



(a) Greenville city Traffic Analysis Zones (TAZs) and AMD region (in light blue part)



(b) zoom in AMD (phase 0 and 1) region

	Greenville	AMD region
# of TAZs	685	8

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

FY 2018 (Previous Accomplishments)

- Preliminary simulations using a hypothetical network
- MOU process initiated with Greenville, SC. Greenville won a $4million U.S. Department of Transportation (DOT) grant to deploy automated taxi (A-taxi) shuttle systems in three neighborhoods
- Received travel demand and traffic network data from Greenville for coding into SUMO.
- Hosted two AMD sessions at the American Society of Civil Engineers (ASCE) — Automated People Movers Conference.

FY 2019

- AMD simulations using Greenville data
- Development of AMD operational configuration optimization module
- Incorporation of mode choice model in the toolkit
- MOU fully executed with Greenville
- Collaborated with Greenville on an National Science Foundation Smart and Connected Communities Grant to build on the AMD work
- Plan to replicate the AMD modeling capabilities in an additional location

Optimization Model

Formulation

- The problem is formulated as a constrained mixed integer program
- Decision variables are integers
- Set of constraints is linear in nature
- Combinatorial problem

Challenges

- General solution approaches include: branch and bound, and cutting plane methods
- Smaller networks can be solved using commercial solvers such IBM CPLEX and Gurobi
- Computational complexity rises with size of the graph (network) and the number of on-demand requests
- Exact solution methods are not scalable for large networks

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

Solution Approach: Tabu Search

- Two-phase heuristic:
  - Initial routes construction
  - Refinement satisfying the constraints
- Provides a feasible and near-optimal solution within acceptable time range.
- To find the minimum number of vehicles required, we start with an upper bound and apply bi-section search to obtain the solution

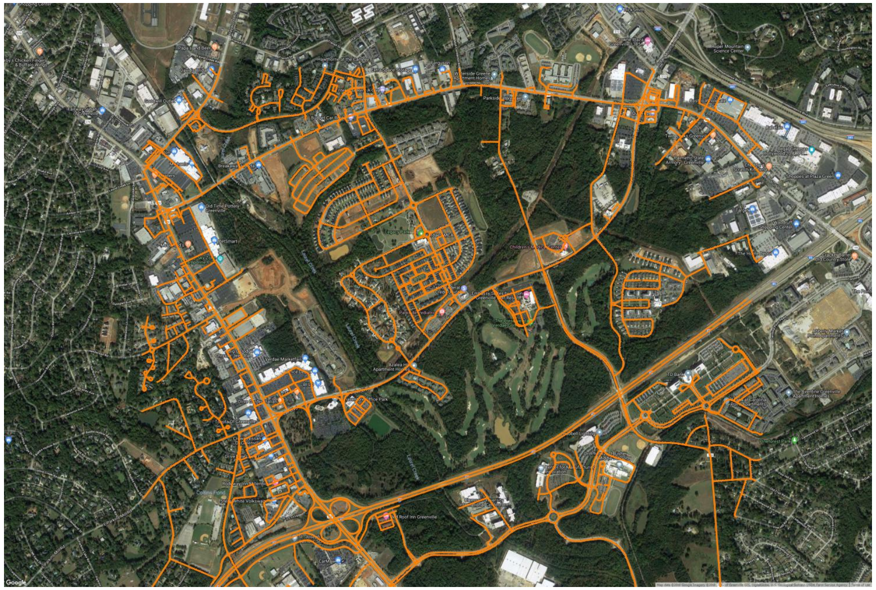
Comparison to exact-solution method

Test case	On-demand Requests	Fleet size	Cost (CPLEX)	Cost (Tabu Search)
A	6	2	48	49
B	6	3	59	59
C	7	2	50	51

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

Case Study: Greenville, SC

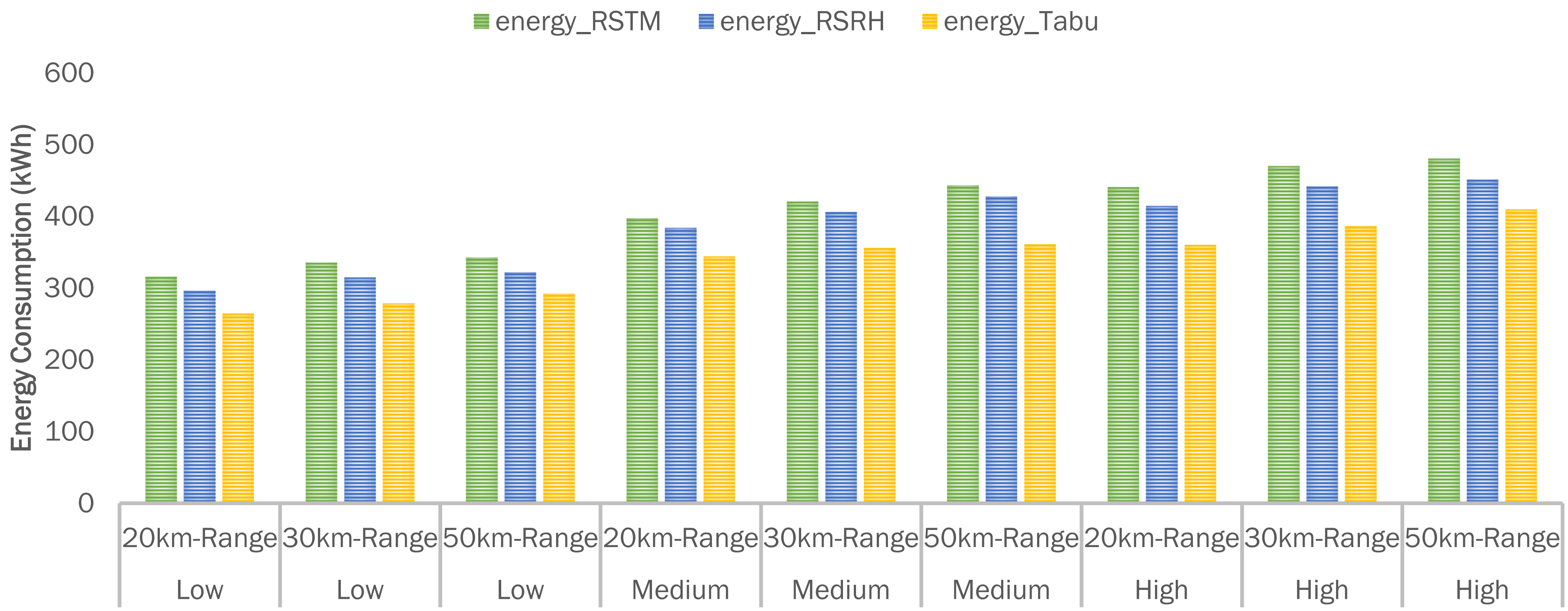
- AM peak hour (06:00--09:00)
  - A total of 378 trips
- Overall mode shares for the experimental analysis are assumed as
  - On-demand A-Taxi (20%)
  - On-demand door-to-door A-Taxi (30%)
  - Walk (10%)
  - Regular car (40%).
- Vehicle design parameters for AES are based on EasyMile EZ10 shuttle14
- Shuttle capacity: {2, 4 , 8}
- AES Range: {20 km, 30 km, and 50 km}



Greenville, SC network has 554 nodes, 1,340 edges, and eight TAZs

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

Findings: Energy Consumption



RSTM: Real-time solution with trip matching (RSTM) does not use any information regarding future demand for the AMD service.

RSRH: Real-time solution with rolling horizon (RSRH) routing uses limited information about future requests from the customers.

Demand: Medium (baseline) ➔ 177 requests; Low ➔ 134 requests (25% ↓ baseline) ; High ➔ 194 requests (10% ↑ baseline)

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: MODE CHOICE MODELING

- **Modes considered in Greenville AMD simulation**

  1) Auto, 2) Walk, 3) AES, 4) Fixed Route

- **General form of mode choice model**

$$V_i = \alpha + \sum_{j=1}^{J} \beta_j x_j$$

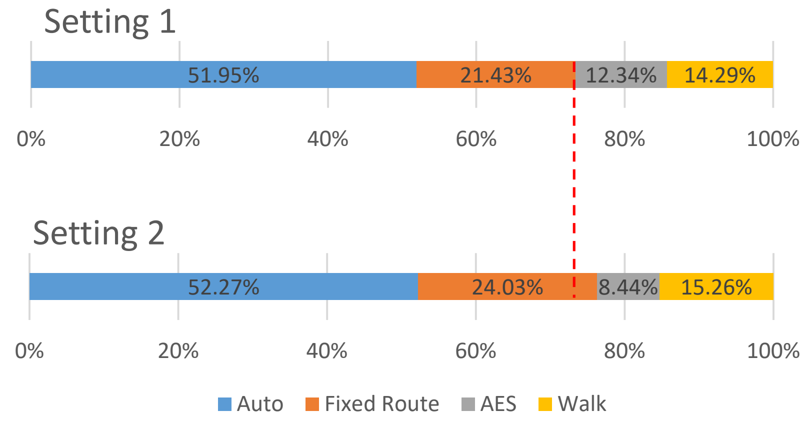
Where
$i \in$ {Auto, Walk, AES, Fixed Route}
α is the constant value
x_j is j^{th} mode choice attribute
βj is coef. of attribute x_j

- **Potential attributes of mode choice model**

1) *In-vehicle travel time (IVTT),*
2) *Out-of-vehicle travel time (OVTT),*
3) *Value of travel distance,*
4) *Fixed cost (fare),*
5) *Others cost, e.g., parking cost*

Example of including IVTT and OVTT

	Value of IVTT ($/h)	Value of OVTT ($/h)
Car	10	0
Fixed Route	17	34
Walk	10	34
AES in Setting 1	**10**	34
AES in Setting 2	**17**	34



- Mode shift observed when value of IVTT changed
- More tests on other attributes in progress

TECHNICAL ACCOMPLISHMENTS AND PROGRESS: AES CATALOGUE

Current	Upcoming
Denver, CO	New York City, NY
Houston, TX	Rhode Island
Arlington, TX	Austin, TX
Las Vegas, NV	Reston, VA
Jacksonville, FL	Battle Creek, MD
Columbus, OH	Columbus – Linden, OH
Ann Arbor, MI	Sacramento State University, CA
Bishop Ranch, CA	Dublin, CA
Gainesville, FL	Rivium Park, Netherlands
Babcock Ranch, FL	

AES #5 Automated Mobility District Database of Pilots, Demonstrations and Deployments

SMART Circuit - Columbus Downtown Scioto Mile Loop

Project Site Data			
AV/AES Site No.		**AES #5**	
Location		**Columbus, Ohio**	
Dates in Service		Dec '18 to Sept. '19	Demo Deployment, Ph. 1
Ownership Data			
Owner/Contracting. Authority		**Drive Ohio (under Ohio DOT)**	
Contact Person -Programmatic		Mandy Bishop (SMART Columbus)	
	Title:	SMART Columbus Program Manager	
	Phone:	614-645-7723	
	Email:	mkbishop@columbus.gov	
Contact Person -Technical		Jeffrey J. Kupko (Michael Baker Intl.)	
	Title:	Assist. Transportation Program Manager	
	Phone:	614-538-7601	
	Email:	Jeffrey.Kupko@mbakerintl.com	
Other Sources/References	**Agency**	Ohio State Univ., Cntr. for Automotive Research	
		Maryn Weimer	
	Title:	Sr. Assoc. Director of CAR	
	Phone:	614-292-5990	
	Email:	Weimer.104@osu.edu	
AES Project Description			
Operating as a low-speed self-driving shuttle, the vehicles circulate around the "Scioto Mile" traversing a 1.4 mile loop route. This is an area in downtown Columbus near Civic Center Drive. The route connects the Veterans Memorial with COSI, SMART Columbus Experience Center			
Cooperating Agencies	DriveOhio, Smart Columbus, the City of Columbus and OS		
Type of Deployment			
Initial Deployment Phase:	Demonstraion Pilot - 6 months		
Subseqent Phases?:	Four other lines are being considered with the second line currently in procurement between St. Stephens and Linden TC		
Status of Project Implementation			
Funding Committed?	Yes. Part of SMART Columbus USDOT grant awarded in 2		
Procurement/Contract?	RFP July 2018, Contract September 2018		
Operational Status?	Service Startup in December 2018		
Time Frame for Project			
Date of Funding:		2016	

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RESPONSES TO PREVIOUS YEAR'S REVIEWERS COMMENTS

- Q5: Resources—How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?
  - R1: The reviewer warned that resources appear to be insufficient to cover the large scope in determining impact of AMDs, and that with larger funding more sites could be explored and modeling correlation could be more robust.
  - Response: The reviewer identifies a pain point that the authors themselves are grappling with. While the scoping of the project was well-intentioned, the resources seem to have been under-estimated. The project team is fully confident in developing a stand-alone modeling and simulation toolkit that can inform early-stage AMD deployments regarding mobility and energy benefits of deploying automated shared electric vehicles. However, integration with a regional travel demand model and application to more sites seem to be a bit challenging under the current funding for the project. The project team's current plan is to:
    - Perfect the optimization module
    - Integrate mode choice model that is responsive to operational (travel time, waiting time etc.,) and infrastructural (parking availability, parking cost) parameters of various modes
    - Apply the toolkit in at least one additional location (on top of Greenville)
  - While we recognize that this is ambitious to achieve, the project team is nevertheless working toward accomplishing this plan by the end of the fiscal year.

COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS

Within VTO

- SMART Mobility Consortium Laboratories: NREL, ORNL, and INL
- SMART Mobility Pillars: Advanced Fueling Infrastructure, CAVs, Mobility and Decision Science

Outside VTO

Collaborators	Type	Extent
Greenville	County/city	AMD deployment partner, providing travel demand and network supply data
Robotic Research	Industry	Automated shuttle operation data from Greenville deployment
University of South Carolina	University	Energy consumption modeling (sub contract)
University of Houston and University of Michigan	University	Potential AMD deployment partners
Mineta Transportation Institute	Non-profit	Coordinating on integrating AMD toolkit with BEAM

REMAINING CHALLENGES AND BARRIERS

- Data availability from real-world deployments
  - Existing deployment is small-scale demos, rather than strategic long-term service offerings.
  - Uber accident in Phoenix altered the timeline and rules of AES deployments. Nonetheless, AES demos are burgeoning.
  - Legal/contractual hurdles in acquiring data required for supporting the modeling toolkit.
- Integration with a regional travel demand model (TDM)
  - Due to delays in long-term real-world deployments of AMDs, in lieu of integration with a TDM, resource was directed to greater AMD intra-district capability, awaiting appropriate opportunity for regional integration

PROPOSED FUTURE RESEARCH

Mode choice behavior studied using actual user survey data

Role of automated shuttles in the context of **micro-mobility** services

Development of a "**network-of-AMDs**" concept

Studying **regional mode choice** impacts

Integrating **mobility energy productivity calculations** into the AMD toolkit.

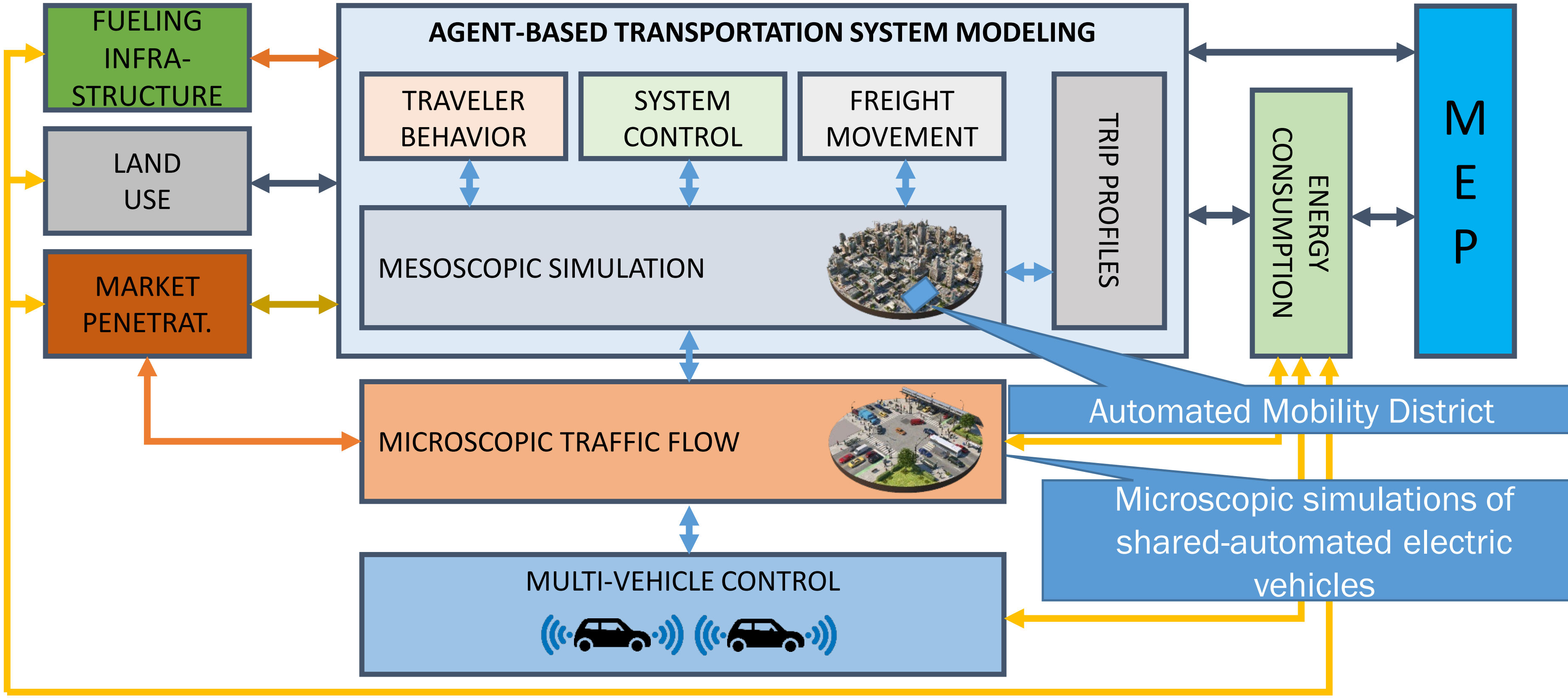
Engagement – Getting the tool into users hands

Any proposed future work is subject to change based on funding levels.

SUMMARY

- **Objective**: To develop modeling capabilities for VTO to estimate energy, emission, and mobility impacts of AMDs
- **FY18 efforts** include modeling and simulation using data from Greenville, SC
  - Used travel demand data and network information from Greenville to develop a Greenville specific AMD simulation.
- **FY 19 efforts to date** have focused on developing an optimization module that can inform operational configuration of automated shuttles in an AMD
- **Remaining FY19 efforts** will focus on:
  - Incorporation of a mode choice model that is responsive to operational characteristics of automated shuttles in an AMD
  - Replicating the AMD modeling process in one location in addition to Greenville
  - Initial steps toward integrating the toolkit into a regional travel demand model (time & resources permitting)

END-TO-END MODELING WORKFLOW

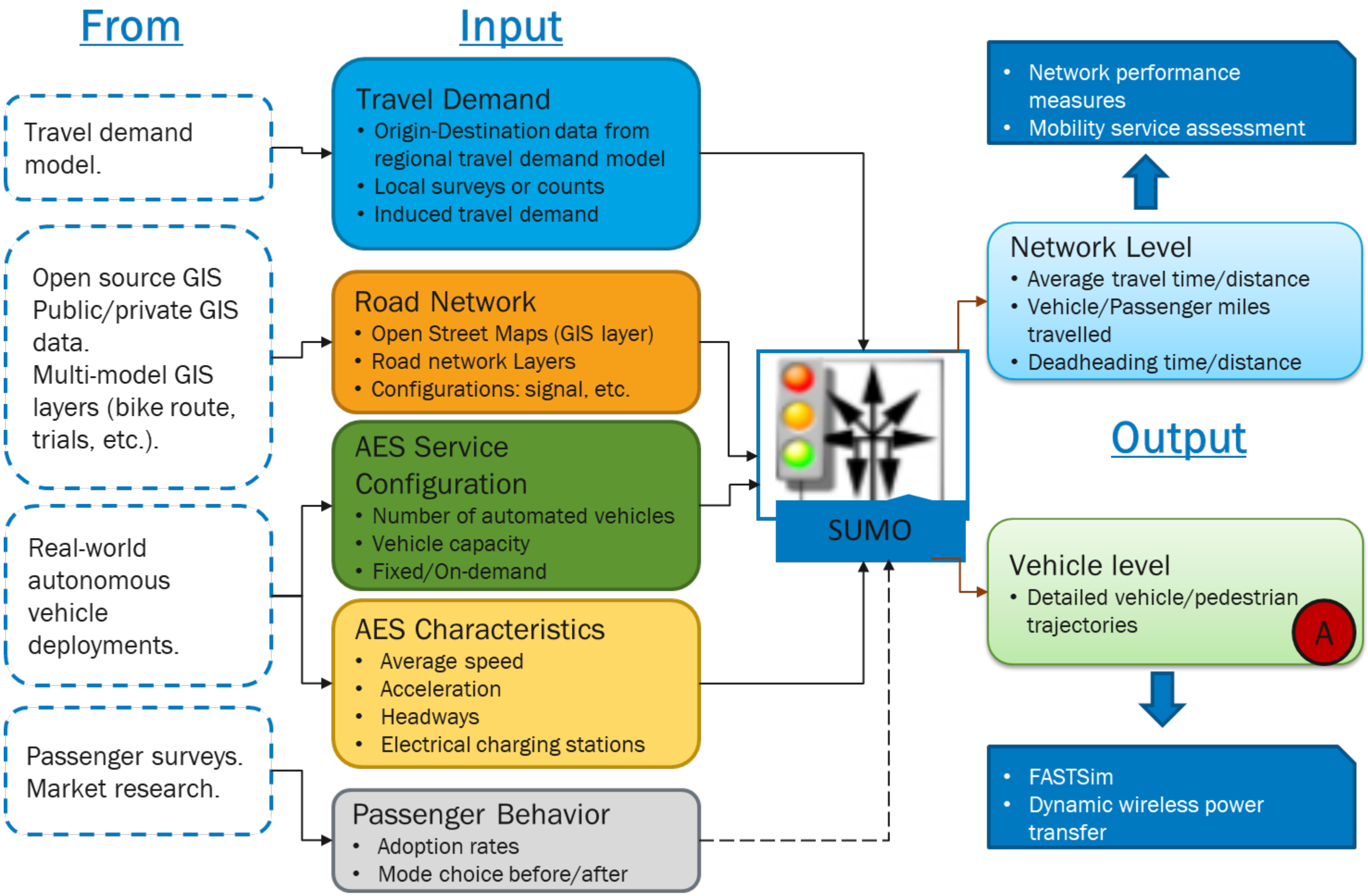


The AMD modeling toolkit will help in the development of microscopic traffic flow simulations to quantify the travel and energy impacts of deploying low-speed automated electric shuttles.

QUESTIONS?

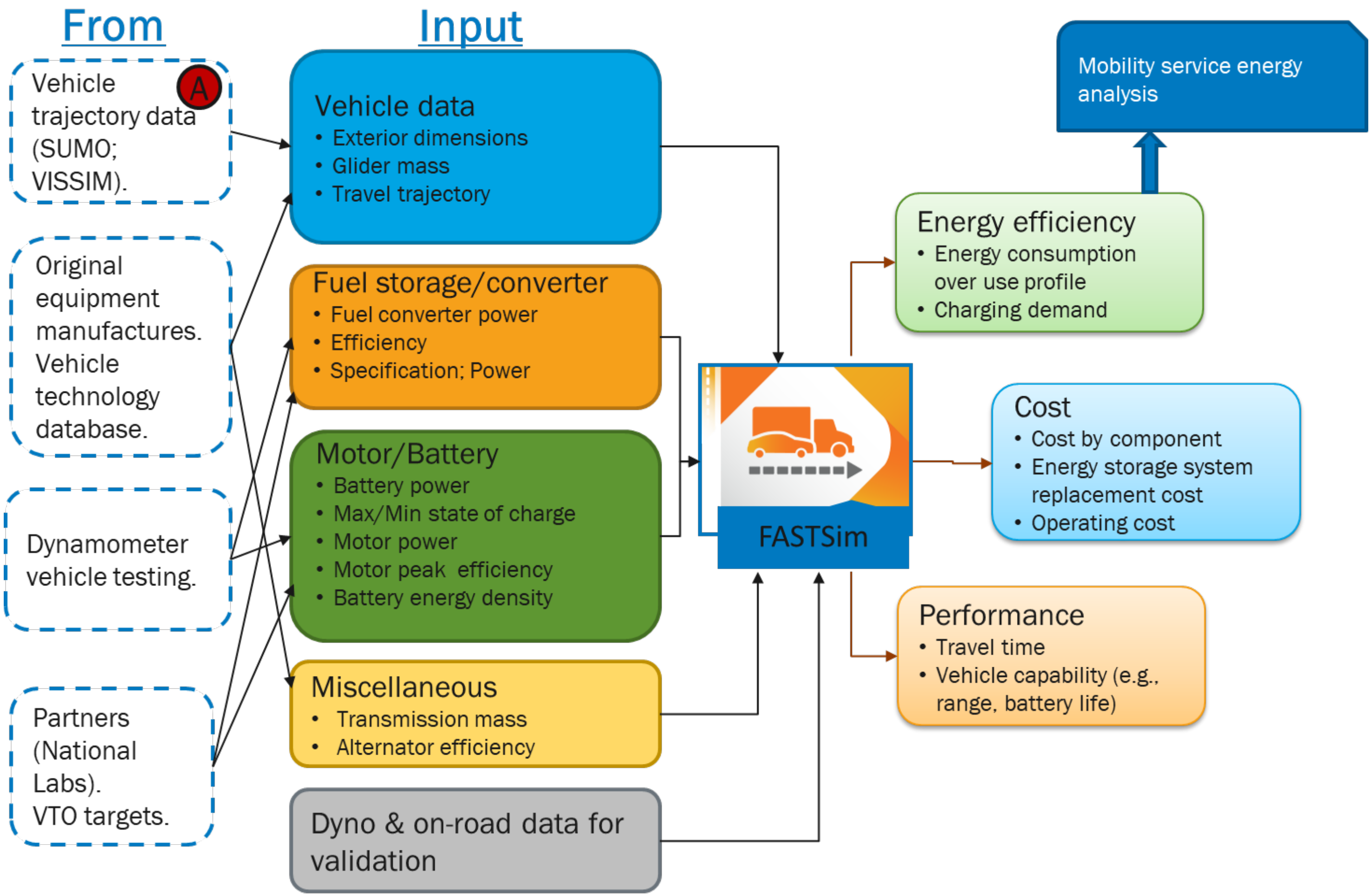
TECHNICAL BACK-UP SLIDES

APPROACH: AMD TOOLKIT – INPUTS/OUTPUTS FOR SUMO



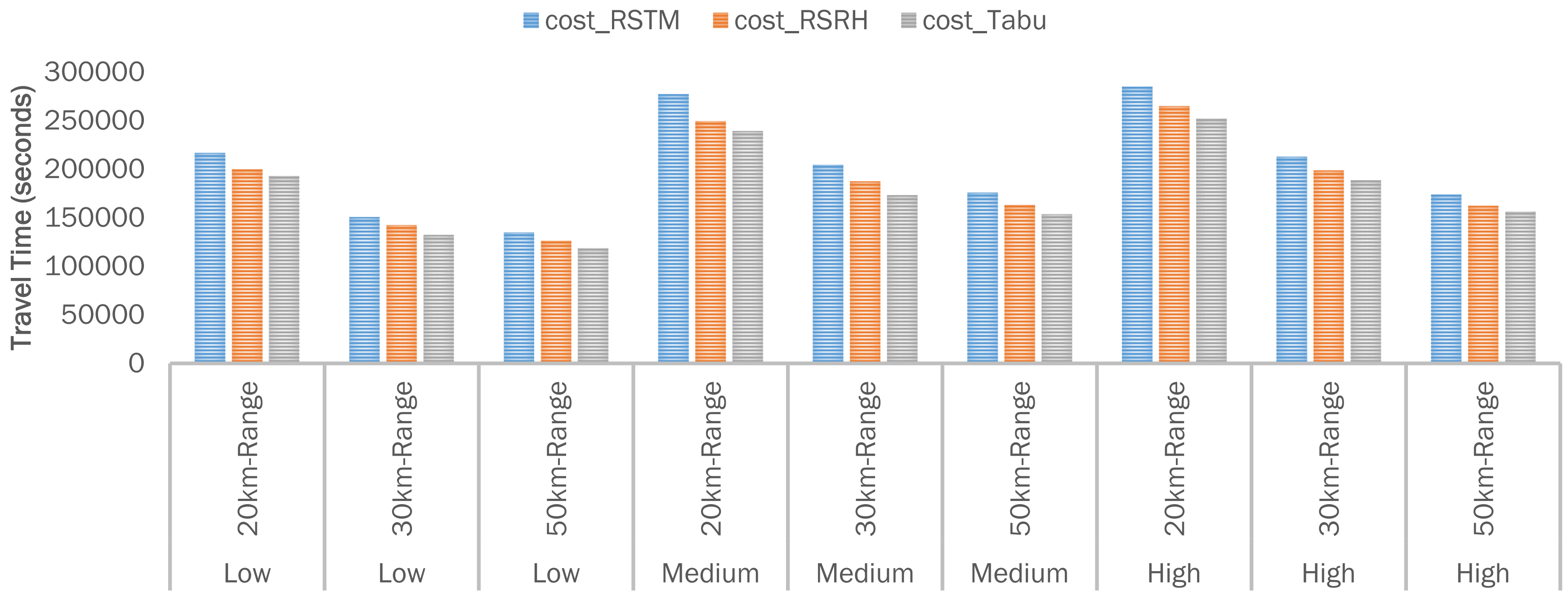
AES: Automated Electric Shuttle; GIS: Geographic Information System

APPROACH: AMD TOOLKIT – INPUTS/OUTPUTS FOR FASTSIM



TECHNICAL ACCOMPLISHMENTS AND PROGRESS

Findings: Travel Time (Cost)



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TECHNICAL ACCOMPLISHMENTS AND PROGRESS: MODE CHOICE MODELING

- AMD simulation working with mode choice model to determine the optimal mode choice ratio under constant demand
  - Mode choice model takes simulation network performance (including regular car and AES)
  - Mode choice model outputs travel mode data as input for simulation